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THE POTENTIAL OF THE COMPUTER AND HIGH-SPEED INFORMATION PROCESSING TECHNIQUES FOR INDUSTRIAL DEVELOPMENT

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THE POTENTIAL OF THE COMPUTER AND HIGH-SPEED INFORMATION PROCESSING TECHNIQUES FOR INDUSTRIAL DEVELOPMENT

D.1.3

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I. Introduction

1. The selection of promising new lines of industrial growth for a developing country is an art which attempts to draw equally on new concepts in economics and new horizons in technology. The needs of the developing areas are more often than not very urgent, and every practitioner in this field who has had to face the responsibility of coming up with recommendations for concrete action in particular cases is perennially seeking for new ideas, new approaches and new alternatives that offer a hope of cutting through the many vicious circles which surround the problem on all sides.

2. This paper is a report of an admittedly summary survey of the new field of high-speed computation and information processing, which has been conducted in search of such new concepts and approaches to the problem of planning industrial growth. The survey has turned up two ideas of great promise: the application of numerically controlled fabrication processes to the end of breaking the constraints which prevent the economical operation of the engineering industries in many of the less developed areas; and the application of a systems approach, based on high-speed computers, to the problem of organizing an efficient information-gathering and decision-making machinery in the field of industrial development planning. Most of the discussion in this paper is devoted to these topics. Other topics, of great interest in themselves but of lesser immediate significance to the less developed areas, are mentioned but briefly.

II. Information Processing: Background

3. In the past decade, a veritable revolution has taken place in the science and technology of information processing. The modern electronic computing machine is the principal embodiment of the resulting advance, as well as the tool for the execution of the many highly complex tasks of data organization, storage and analysis which can now be successfully handled. It has been estimated that the capabilities of such machines have increased by several orders of magnitude over the past decade and a half, in terms of speed, memory capacity and reliability. The costs of the machines have increased concurrently at a much slower rate; thus, both the time and the resources required for the performance of a given data processing task have declined considerably.

4. Meanwhile, the difficulties of programming the computer (i.e., giving instructions to the machine) have been greatly reduced for a number of important areas of application, including mathematical calculations and the handling of textual material. This has been achieved by creating special codes which resemble closely the technical terminology ordinarily used in each one of these fields; the codes themselves are in such a form that they can be accepted directly by the computing machine as commands for the execution of complex series of operations. By this means, the computers have been made accessible to a wide range of potential users.

5. The principal payoff on the application of computers has so far come in

data reduction, i.e., in the digestion of enormous volumes of numbers for drawing specific conclusions. A spectacular example is the tracking of artificial satellites. Many complex mathematical computations also have become practical for the first time. Recently, information processing systems based on electronic computers have been introduced for the replacement of routine clerical effort in commercial organizations, i.e., the clearing of bank cheques, the calculation of payrolls, certain accounting functions, etc. Currently, a large new field of expansion is in the control of physical operations in the manufacturing industries, both in fabrication and in continuous-flow processes; and in the design and operation of complex interacting systems such as are encountered, for example, in the management of business firms.

6. From the point of view of the less developed areas, the control of fabrication processes by means of the techniques of information processing is of especial interest, since it promises to open up a major new avenue of industrial development. This technology is referred to as numerical control. The following sections will be devoted to this topic. Thereafter, other direct contributions to industrial production will be briefly mentioned, including on-line process control and operations scheduling. Finally, the contributions of information processing to the techniques of planning and decision making in the field of industrial development will be discussed.

III. Numerically Controlled Fabrication Methods

7. Numerical control of a fabrication step signifies the automatic execution of operations by a machine on the basis of commands coded in a punched paper tape or other information-carrying medium. For example, a numerically controlled milling machine or other machine tool will execute a complex series of metal cutting operations which have been decided upon in advance by the designing mechanical engineer. High-speed computing machines intervene in translating the physical design into coded instructions which prescribe the behavior of the machine from moment to moment in minute detail, including position, speed, feed rate, tool and coolant selection, etc. After the coded control tape has been prepared, a part can be produced automatically at any time without further human intervention except, usually, the loading and unloading of the machine.

8. Numerical control is available at present for most metal cutting machine-tool operations, and for a variety of other fabrication processes, including pipe and tube bending, motor and coil winding, flame cutting and seam welding, riveting, various kinds of assembly, and the inspection of products. Applications contemplated for the near future include forging, stamping, extrusion, wire and strip bending and many other operations.

9. In 1961, there were about 2000 numerically controlled machine-tools installed in the United States; sales totalled 100 million dollars, representing one-sixth of all machine tool sales. Yearly sales have approximately doubled from year to year; it is forecast that by 1965 anywhere from one to two-thirds of all machine tool sales will be of the numerically controlled type. At present, there are about sixty manufacturers of numerically controlled machine tools and about half that many of control equipment.

A. Advantage of Numerical Control

10. Numerically controlled fabrication methods promise to enlarge greatly the range of metal transforming and fabricating industries that can be operated economically in many of the less developed areas. The principal factors tending to produce this result are: (a) a drastic lowering of the minimum economic scale; (b) a reduction of the level of operator skills required; (c) a guarantee of uniform product quality; and (d) an achievement of these benefits at favorable unit capital costs. The difficulties which will have to be overcome in bringing this promise to fulfillment are considerable, but the potential benefits are so great that a large effort is well worth while.

11. The discussion is centered on numerically controlled machine tools, since

they furnish a good example both of the advantages offered by numerical control and of the problems raised by it. Moreover, the best information is available in regard to these machines.

(a) Minimum Economic Scale

12. The reduction of the minimum economic scale is the result of the high productivity of numerically controlled machine tools which is not dependent on production runs consisting of large lots of identical workpieces. Numerical control is characterized by extraordinary flexibility in production. Special tooling, jigs, fixtures and templates are almost completely eliminated, since the control tape automatically positions the workpiece in relation to the cutting tool for each cut, with a high degree of accuracy. As a consequence, the time required for setting up a production run, or for changing over from one run to another, is reduced from hours or days to minutes or even less. Thus the two principal dis-economies connected with the production of small lots are eliminated; namely, the high unit cost of jigs, fixtures and special tooling, and the high unit cost of set-up time.

13. The advantages of numerical control in respect to economics of scale have to be evaluated in relation to two types of conventional operations: the job shop, producing a large variety of products on standard machine tools, in relatively short series (typically, from a few pieces to a few hundred pieces per lot, occasionally more); and the mass-production plant, producing thousands of identical or nearly identical pieces on specially designed and built machine tools rigidly coordinated into production lines. In assessing the relative significance of these two types of production, it should be noted that in the United States about three quarters of the dollar value of all metalworking products originates in series of twenty-five units or less. Numerical control leads to a drastic cost reduction in the production of job shop products, and it can virtually eliminate cost differences between shorter and longer runs within this range. Thereby, one of the key disadvantages of the less developed areas in the manufacture of such products, stemming from the narrowness of their local markets and correspondingly high unit costs resulting from the use of conventional techniques, is largely overcome.

14. Turning now to a comparison with mass production, it is generally conceded that under conditions such as prevail in the United States, numerical control results in higher unit costs. In certain circumstances, nevertheless, the capital investment in numerically controlled machines for producing the same volume of output may turn out to be approximately equal to that of conventional mass-production equipment, and in this case the cost advantage of conventional mass production is primarily due to labor savings. This may happen when a flexible numerically controlled operation is able to replace more than one independent mass production line. Little experience is available on this point, and professional opinions differ. It is, however, not in doubt that the flexibility of numerical control is often highly attractive in comparison with the rigidity of a mass production line; this is an especially significant consideration when engineering improvements and model changes on a product are frequent or when the market is unpredictable. Thus, by reliance on numerical control techniques, the less developed areas may find it possible to compete even against certain types of mass production, without finding themselves at nearly as much of a comparative disadvantage as they customarily encounter at present. More significantly, in the manufacture of such products, the productivity of their scarce capital resources can be raised close to the level attainable by mass production in the broad markets of the industrialised countries.

(b) Operator Skills

15. Numerical control reduces the need for highly skilled operators. Whereas the hand operation of machine tools, especially of the complex and high-precision types, has the nature of a craft which is perfected during a lifetime, the operation of numerically controlled machinery primarily involves, beside loading and unloading, chip clearing and changeover, the monitoring of the machine for the regularity of its mechanical performance. The required level of skills is therefore lowered, even though the job is a responsible one. Moreover, the need for

job classifications corresponding to specialized classes of machine tools disappears, as the nature of the work is identical in all cases. As a consequence of these two factors, the adoption of numerical control techniques reduces the pressure of the scarce skilled-labor resources of the economy: the lower-level skills required can be provided by means of a much shorter training period. Furthermore, the elimination of job classifications permits the shifting of workers between machines, thereby reducing absenteeism problems. Work incentive plans can also be eliminated and replaced by flat rates, since the rhythm of operations is fully determined by the control tape.

16. In sum, the limitations of scarce skills on the growth rates of the economies of the less developed areas become less binding.

(c) Product Quality

17. Numerically controlled machining has the advantages of consistently high quality. Tolerances are coded into the control tape and automatically maintained. This results in a high degree of accuracy, repeatability, and in an excellent mutual fit of workpieces during assembly. The effects of worker fatigue are eliminated; spoilage is greatly reduced, to the point where the entire nature of quality control can be changed, at substantial savings. Apart from sporadic tool breakage and comparable accidents, no rejects are produced; therefore, a major proportion of inspection effort can be dispensed with, and replaced by a periodic inspection of the machines themselves rather than of the parts produced.

18. Consistently high product quality makes numerical control especially suited to the conditions of the less developed areas, since at present the problems of quality are of perennial concern and discourage the initiation of many lines of manufacture.

(d) Capital Productivity

19. Numerical control leads to greatly increased productivity of capital when compared with job shop production, and compares rather favorably even with conventional mass production techniques, as pointed out earlier (see paragraph 14).

20. Individual numerically controlled machine tools are more expensive than their conventional counterparts, but comparison is often difficult, since numerical control leads to a change of functions, in the direction of greater universality of the individual machine. The price differential ranges anywhere from 25% to 100% and even 200%, depending on exactly how much auxiliary equipment is included in the comparison. The technical development of these machines is also very rapid; there is a wide range of alternatives on the market, from conventional machines adapted belatedly to numerical control, to modern machines conceived from the beginning for full integration between operational and control functions.

21. Unit capital costs are favorable, since the productivity of a machine is generally increased by more than its price, and there are additional capital savings on account of floor space and inventory.

22. The largest improvements are due to an increase of the fraction of shift time the machine is actually engaged in removing chips. For conventional operations, this ratio is of the order of one quarter, on the average, while with numerical control it increases to the order of three quarters. This better utilization is due to the very short set-up and change-over times, the versatility of the machines which permits a larger number of operations on a single machine, thereby cutting down on the shuttling of workpieces between machines and the resulting bottlenecks on some machines and slacks on others, and the fact that machines in conventional job-shops are often kept idle in order to save a particular set-up. Such an improvement in machine utilization is especially significant because cutting speeds have been increased already to the limit with conventional equipment, and little remains to be gained in that respect; still, numerical control shows some gain on this account also, due to higher speeds near the edges and corners of the workpiece and generally, in the late stages of a complex and expensive job, where a human operator would tend to proceed with extra caution.

23. Savings in floorspace are a direct result of higher machine productivity and lower in-process inventories; moreover, the versatility of the individual machines decreases layout problems. Both floor space and inventory savings are also obtained because a piece is fully machined in a short time with less of the usual queuing and accumulation of workpieces on the production floor between machines. In addition, inventories of finished products can also be kept at a very low level, since additional pieces can be easily run off as needed by use of the existing control tapes.

B. Problems Associated with Numerical Control

24. The advantages listed above appear almost too favorable to be true; and, in fact, there are some serious problems to be overcome before the full payoff on numerical control can be obtained in the less developed areas. Given a sufficient effort, however, numerical control does in fact offer a technological means of breaking through the customary vicious circles posed by restricted markets, missing skills, and the scarcity of capital goods.

25. The principal problems arise from (a) the minimum scale required for running a numerically controlled production system (as distinguished from the scale of production of a single product); (b) from requirements for new skills; (c) from the need for special attention to machine reliability; and (d) from the fact that a large plant of the kind envisaged, which could take full advantage of the benefits of numerical control, represents a genuine technological innovation.

(a) Scale of System

26. The full benefits of numerical control are difficult or even impossible to realize on a gradual basis in the less developed areas, since numerical control has to be applied to a wide range of individual operations before any finished product can be produced largely by this technology. Some operations, like the production of nuts and bolts, will probably never be worth performing by numerical control, but even so, the variety of operations involved in fabrication and metal-working is large enough to make an integrated numerically controlled plant a major industrial unit. The productivity of such a plant is enormous, and keeping it running around the clock poses the basic problem. Even in industrialized countries, two-shift operation of numerically controlled equipment is practically mandatory for economic reasons; in the less developed areas, it would be a major waste of capital productivity to run anything but three shifts. No detailed studies have been made of the necessary demand for products to keep such a facility busy, but it can be predicted confidently that even without the need for making any one product in large lots, the scale of the operation as a whole will easily surpass the demand available within the borders of many smaller countries. Thus, while the dis-economies of small scale can be overcome by means of numerical control in so far as individual products are concerned, they persist in relation to the production volume as a whole. Therefore, only the larger or higher-income countries will be able to set up such facilities on their own; for others, the only feasible approach seems to be a common effort. Moreover, it is evident that in many cases the necessary demand can be guaranteed only by means of a careful planning and coordination of a large variety of production lines which, in the highly industrialized countries, are customarily classified and organized as separate branches of the manufacturing industries. For example, it is entirely possible that the minimum scale requirement cannot be met without channeling portions of the production of agricultural equipment, automotive products, electric sub-assemblies, industrial equipment and consumer durable goods to a common facility of the kind indicated.

27. Economies of scale in relation to the system as a whole also arise from unified engineering design facilities and the sharing of electronic computing equipment. The huge productivity of the plant requires a very large engineering design effort, maintained on a steady basis, in order to provide control tapes for the operation of the machines. Initially, this requirement may perhaps be circumvented to some extent by obtaining control tapes from abroad, either in the form

of technical assistance or on a royalty basis; nevertheless, the full benefits of modern technology cannot be realized unless engineering design is steadily improved and adapted to local conditions. Thus, while tapes from abroad may be useful for starting up a plant, they cannot be relied on indefinitely.

(b) New Skills

28. While numerical control eliminates the need for operator skills, it creates a requirement for specialized maintenance, engineering design and management skills.

29. Maintenance skills involve experience in hydraulics, electronics, relay circuits and servo systems: they require specialized training of a higher level than the displaced operator skills, but the number of man-hours needed per unit of production is of course considerably lower, leading to a net saving of scarce skills. The requirements for skills in engineering design, control tape coding and production planning are, however, very large. The preparation of machine instructions from a finished design has been reduced from a ratio of 12 hours per hour of machine operation to a ratio of about 1:1, by means of powerful summary coding techniques which are translated into detailed machine control tapes by electronic computers; none the less, the total effort required is still very large, especially if the lots run off from each control tape are small. No doubt, the provision of a large pool of engineering talent for design and coding will raise considerable difficulties in many of the less developed areas. In many countries it may, however, be easier to train mechanical engineers than skilled craftsmen; moreover, it is logical that whatever pool of engineering talent does in fact exist, should be channelled toward occupations of the highest productivity. It should be added that major progess is now underway in the fields of computer-aided engineering design, numerically controlled drafting and several related fields, which promise to free the engineer from many routine functions, and also to reduce sub-professional staff requirements considerably.

(c) Reliability

30. A further problem is raised by special requirements for maintaining machine reliability. This includes some added investment costs, such as heavy foundations (to guarantee perfect leveling of the machines), or temperature and humidity controls (to eliminate a drift in tolerances). Preventive machine maintenance, as well as the regular sharpening and pre-setting of tools, becomes a necessity. All raw materials, whether purchased or internally produced (bar stock, sand-blasted castings, forgings, etc.) have to be as uniform as possible, since there is no way of making compensatory adjustments when the operations are under tape control. These factors place a special premium on competent management.

(d) The System as an Innovation

31. A large numerically controlled fabrication plant constitutes a highly complex system which has the nature of a genuine technological innovation. In the United States, numerically controlled machines have been introduced little by little into existing operations; in the less developed areas, however, the benefits of numerical control cannot be captured except by means of an integrated large production facility (see paragraph 26). The advantages of integrated systems over isolated machines have been strongly emphasized even for the industrialized countries: it has been conjectured that so called "system benefits" outweigh individual-machine benefits by perhaps as much as 2:1. It is of course true that in the industrialized countries, all kinds of fabricated metal products and machinery have been produced successfully for many years by conventional techniques; thus, there is less to be gained by the new technology than in a context where the need is desperate and the conventional methods largely inappropriate.

32. There has been little experience so far with systems of numerically controlled machines. In the United States, several large operations exist which incorporate as many as a few dozen numerically controlled machines; also, there are some small facilities entirely under numerical control. No integrated large plant of the type envisaged here, however, has yet been built.

33. Such a plant, with perhaps 50 numerically controlled units, would represent an investment of 5-7 million dollars in numerically controlled machines alone. Compared with the first cost of an integrated steel mill, this is not a frightening sum, but undoubtedly it represents a major commitment for any of the less developed areas.

34. The managerial skills needed for running such a plant are considerable, since there is a large penalty on operating the plant at less than full capacity. In designing a suitable system around numerical control, however, many powerful management control concepts and aides become available for the first time. The need for time studies, complex inspection systems and wage incentive systems disappears. Accounting is greatly simplified, since engineering design is translated into finished parts almost error-free; thus, estimates coincide closely with accounting figures. Production control is simplified, since much of the customary preparation of shop drawings, blueprints, inspection sheets and routing papers is replaced by direct commands to the machine through the medium of the control tape. Shop scheduling is also simplified, due to the diminished shuttling of pieces between machines. At the same time, however, whatever scheduling is still needed becomes more critical, due to the high premium on full-capacity operation; and the scheduling of preventive machine maintenance and tool control acquires an extraordinary significance.

35. All these factors point up the need for a careful preliminary study of such systems before commitments are made, and the design of each plant on the basis of up-to-date organizational and scheduling methods. It also appears that in many of the less developed areas, the proper way of establishing such a facility is by starting it up with a competent temporary foreign staff which is subsequently replaced as rapidly as possible by local personnel trained on the job.

C. Benefits of an Engineering Industry

36. The possibility of manufacturing economically a wide range of metal transforming and fabricated products in the less developed areas has such obvious consequences for their economic development that it is hardly necessary to dwell on these consequences in detail. With a domestic industry capable of turning out machinery and equipment at a reasonable cost in terms of scarce resources, these areas will no longer find their potential savings dissipated and their growth strangled by foreign exchange shortages on the one hand and formidable dis-economies of capital goods production on the other. The domestic manufacture of a variety of capital goods, consumer durables and transportation equipment will, in any event, reduce the pressure on the balance of payments, and will thereby contribute to the possibility of importing those commodities whose domestic manufacture would be the least economical or entirely unfeasible.

37. A numerically controlled facility could make also an important contribution to improving the availability and reducing the cost of spare parts for imported engineering products. Given the cooperation of the manufacturers in the industrialized countries, it would no longer be necessary to carry large inventories; if the control tapes for the parts were made available, the parts could be produced locally as needed. As a long-term benefit, this would lessen the burden on a country of importing needed engineering products, and would thereby incidentally facilitate the marketing of such products. As a short-term benefit, it would permit coping with the exasperating array of engineering products of all types, brands and makes that now flood the markets of many of these areas. At present, the lack of availability or delay in obtaining needed spare parts, often due to foreign exchange problems, can lead to the idling of expensive productive machinery for long periods of time.

IV. Other Contributions of Modern Information Processing to Industrial Development in the Less Developed Areas

A. On-Line Process Control

38. The control of operations by means of computers in the process industries, so-called on-line process control, is a recent development in the industrialized countries. The purpose of this control may either be the optimization of process

variables in a highly complex, dynamic interacting system, to the end of obtaining better yields or higher qualities; or else, computer control may be introduced with the end of safety in mind - e.g., for the complex start-up and shut-down operations required in thermoelectric power stations, where the penalty on operator error can be a major accident. No doubt such computer control will in due course find its way into new plants built in the less developed areas, but it does not hold out the promise of any dramatic breakthrough, such as that indicated in the foregoing sections in relation to numerically controlled fabrication processes.

39. An interesting indirect benefit may, nevertheless, result from this new technology in the following way. On-line computer control promises to yield its greatest payoff in industrialized countries when totally integrated with a process from the beginning of design, rather than when added on as an afterthought to standard processes. In this way, it may have the effect of unfreezing standard engineering practices, with the hopeful consequence that engineers in industrialized countries will acquire more of the mental perspective which is needed for fresh approaches to the otherwise entirely different problem of capital-labor substitution, where progress so far has been minuscule.

B. Operations Scheduling

40. On-line process control, when applied to semi-continuous processes such as characterize for example the steel industry, merges into another new development connected with computers and information processing, namely, operations scheduling. This is the art of improving the efficiency of batch-type or semi-continuous operations subject to elements of uncertainty, by means of improving machine utilization, reducing materials handling, transportation and inventory requirements, improving product quality, and other related means. Operations scheduling depends on the careful analysis of mathematical models; this analysis, in turn, depends on high-speed electronic computers for all but the simplest kind of industrial situations, since the models become too large and involved for handling by any other means.

41. The importance of operations scheduling has been pointed out earlier (see paragraph 34) in connection with numerically controlled fabrication processes. In other applications, it also promises an improvement of productive efficiency; this is especially significant from the point of view of the utilization of scarce capital resources in the less developed areas. There are, however, limits to what operations scheduling can accomplish under the conditions typically prevailing in many of these areas. The efficiency of a given productive unit (plant, firm, organization) depends on two separate sets of factors: the internal ones, under the control of the unit, and the external ones, outside its control. Even with perfect internal operations scheduling, the productive unit can be at the mercy of such external destabilizing influences as tardy shipments from suppliers, unreliable qualities of purchased commodities, inability to obtain spare parts for vital machinery when needed, unpredictable changes in foreign exchange or licensing regulations, etc. In addition, many productive units are also burdened with misdirected investments.

42. Productive units which attempt to increase the efficiency of their internal operations under these conditions will often do so by isolating themselves, in so far as possible, from outside disturbances. This can be achieved by increasing the self-sufficiency of the unit: the integration of related functions, the increase of inventories of raw materials, supplies and spare parts, the acquisition of machinery for performing specialized operations that are needed only occasionally, etc. This strategy will succeed in raising internal efficiency, but only at the cost of increasing substantially the capital tied up in the process. Thus, it is not the best strategy from the point of view of industrial growth in the economy as a whole, since it raises the capital-output ratio.

43. Operations scheduling for the individual productive unit cannot improve on this outcome; the only effective way of handling the problem is to center the attack on the interrelations between productive units: in other words, to carry operations scheduling beyond the confines of the individual productive unit. This is entirely feasible, and in fact, it constitutes one of the important avenues of action in the

purposeful planning of industrial development.

V. Contributions to Industrial Development Planning

A. The Nature of Industrial Development Planning

44. The planning of industrial development involves an enormous task of information processing. The economy as a whole, and its industrial sector in particular, can be regarded as complex interacting systems. Government entities which take actions of economic significance (including public enterprises) and private firms make up the economic system. In particular, all entities with planning functions are also part of this system. The latter entities, however, are peculiar in this respect: they form a subsystem whose action and functioning is governed by policy objectives concerning the economy as a whole.

45. A great deal of advance has taken place in recent years in regard to the principles which govern the flow of information, the maintenance of centralized memory files, the division and interaction of functions and many related matters in the efficient management of large systems. Admittedly, no systems so far studied have exhibited the complexity of an entire economy or of one of its sectors. On the other hand, the purpose of studying the economic system from the point of view of industrial development planning does not embrace the problem of managing the entire industrial economy in all of its detail. A major portion of this detailed management is typically left to independent decision-making units, which may have the nature of private firms or of largely autonomous public enterprises. This reduces to reasonable proportions the task of studying the interrelations between the overall system and the planning subsystem.

46. Thus, in general, the planning subsystem will have a hierarchical part and a part comprising the collection of independent decision-making units. Planning for the system as a whole reduces to the spelling out of consistent policy objectives at the top decision-making level of the hierarchical part; in adequate communications up and down the line with the lower hierarchical levels, and an interaction between top-level and lower-level policy objectives; and in the establishment of a mechanism that will bring an adequate structure of incentives and constraints to bear on the independent decision-making units, so as to assure that their general behavior will be consistent with overall policy objectives, while maintaining their freedom of adaptation to detailed environmental conditions.

47. Planning in the above sense requires: (a) the establishment of an orderly pattern of information flow; (b) the analysis of this information, to the end of deriving policy objectives; and (c) the design of an integrated mechanism of policy execution and error correction, consisting of a network of functions and controls for the hierarchical part, and of a pattern of incentives and constraints for the coordination of the part consisting of independent decision-making units.

(a) Organizing a Pattern of Information Flow for Planning

48. Information for industrial planning purposes comes from a variety of sources. Basic data on economic conditions and on the operation of the productive system are supplied by the usual statistical efforts. In addition, data are also needed on technological relationships and input-output flows between different productive processes which are not customarily provided by the traditional censuses and sample surveys. In part, they can be obtained from local sources; in part, they may, however, have to be obtained from foreign technical sources, since data are needed on potential new production processes not yet established in the area. A most important category of information originates in the fiscal, regulatory and planning agencies of the government, and in public enterprises: tax returns, foreign trade data, project descriptions submitted with loan or import license applications, data on electric consumption, freight movements, etc.

49. Information is seldom used for planning in the form in which it is gathered. From the point of view of an efficient information system, however, all the original data needed for planning, whatever their source, should be recorded as soon as possible in a code directly acceptable by machines. A key task is the

establishment of a unified system of memory files to which all authorized units of the subsystem have access for purposes of use and updating, in order to avoid the duplication of effort in maintaining and revising the same information in several different places. Most actual organizations furnish numerous examples of such duplications of effort, and the operations of governments abound in them. It is typical that the files of one department are inaccessible to other departments, and the extraction of needed information from a variety of jealously guarded archives poses a major difficulty and constant delay. The systematization and mechanization of keeping such files is indispensable for handling the larger volume of information required by increasing planning efficiency: the information needed increases both in detail and in frequency of revision. This puts a considerable load on all elements of the information system, including the contacts with the original sources.

50. Data can be extracted from the memory files and consolidated in any required manner, rearranged and otherwise processed by punched-card tabulators or electronic computers. Given the volume of data to be handled and the flexibility required in handling, computers are almost certain to be required. This becomes even more of a necessity when some of the files are set up for joint use by the planning subsystem and some other government agencies.

51. Much experience has been accumulated in recent years in regard to the organization and physical embodiment of efficient information gathering, storage and presentation systems. Most of this experience can be brought to bear, without significant revisions, on the design of unified information systems for industrial development planning.

(b) Data Analysis and Policy Formulation

52. It is often affirmed that the data gathered in any of the less developed areas are subject to so much error that they will not support adequately a sophisticated mathematical analysis, such as input-output work, linear programming or simulation. This is indeed a justified observation in many cases, but at the same time, admittedly the only way of checking such data for consistency at all levels is to subject them to the discipline of mathematical analysis. The inconsistencies revealed by such experimentation will permit concentrating the effort of data collection and checking into the trouble spots identified by the analysis. Thus, through a series of trials and revisions, the basic data flow on which the planning process rests will acquire a more and more firm reliability.

53. A variety of analytical approaches are available to the problem of formulating policy models which have been extensively discussed in the economic literature and will not be repeated here. Present high-speed computing techniques permit the solution of very large policy models of the linear programming type. Unstructured models of over a thousand rows and almost any desired number of columns now can be solved by standard procedures, and considerably larger models can likewise be attacked successfully if it is possible to identify some internal structure which will permit the application of decomposition or other shortcut methods. Typically, the models derived from economic situations are highly structured, and this practically guarantees that some feasible approach can be found to the solution of any linear policy model once it has been successfully formulated. In special cases, such as models with large amounts of locational and transport structures, solutions to problems with tens of thousands of rows have actually been obtained.

54. Nonlinear models which arise in planning can be solved also by standard algorithms when the nonlinearities involved correspond to decreasing returns to scale on some process or resource use. The converse case, increasing returns to scale, has posed the most untractable problems until recently. This case is, however, of major importance in some models pertaining to the less developed areas, since it arises in problems embodying minimum economic scales. Lately, these nonconvex problems have become accessible to so-called integer programming, which approaches nonconvexities by means of solutions in terms of integer values of variables. Integer programming models close in on their solutions from the "far" (dual) side, starting with large overshoots and decreasing these step by step until the exact optimum is attained. Experience with the existing algorithms indicates

that they converge rapidly to values near the optimum, but often go through indefinite numbers of iterations from this point on with very little further progress. The early convergence, nevertheless, is seen to create a bound on the far side of the optimum. A sampling of feasible solutions to the problem, all of them on the "near" side of the optimum, can thereafter be used to create the opposite bound; thus, the interval between the two bounds contains the optimum and limits its possible error. Good approximations can be hoped for by this double-barreled strategy in most cases.

55. An entirely different approach to model building is the so-called simulation technique, which has been developed originally for use in connection with production scheduling and other business policy problems. Simulation also relies on the use of high-speed electronic computers. It permits the inclusion in the model of probability distributions, time lags and other realistic but mathematically difficult features which generally preclude an analytic solution. Instead of attempting to obtain such a solution, the simulation model explores the time path of development of the model in full detail, for a selected set of policy variables. Repeated runs with different sets of variables can be used to explore some of the interesting combinations, but simulation models do not have the power of cutting across enormous combinatorial possibilities directly to an optimal solution, like optimizing models do. A combination of the two approaches may offer the best choice in a particular situation.

(c) Design of an Integrated Planning Subsystem

56. Mathematical models for policy formulation in industrial development planning have been available for some time. There is, however, a major gap between the concept of a policy model, on the one hand, and the concept of an integrated planning subsystem, on the other. While a policy model is a mathematical construct, a planning subsystem is a network of organizational entities with definite functions and interrelations. Within this subsystem, policy formulation takes place at various hierarchical levels of regulatory activity, generally on the basis of policy models formulated for this purpose. Policies are then translated into concrete executive actions at each level; for example, at the level of an overall planning office and of ministerial planning organs. The executive actions are in part direct managerial decisions; i.e., pertaining to investments in certain key public projects; in another part, they are indirect, defining a pattern of incentives and constraints for the independent decision-making units to which a large portion of the detailed managerial responsibility within the economy is delegated; e.g., the pattern of certain protective tariff rates. Some actions may have an intermediate character: for example, the authorization of a loan by a government development bank to one of the independent decision-making units. All these actions impinge directly or indirectly on the overall economic system. Subsequently, changes will take place in this system as a whole, in part as a result of these actions, and in part due to exogenous factors. The changes are registered in the form of a new inflow of planning data through the information channels to the planning subsystem. The changes are reflected in a reformulation of the policy models and a revision of policy objectives; they are then translated into a new set of executive actions, repeating the cycle.

57. The above description is meant to illustrate the system character of industrial development planning; the actual interrelations within a planning system are likely to be broken into more levels and stages and, in general, are apt to be quite a bit more complex.

58. The experience available with the design of the simpler systems that have been studied so far indicates that it is possible to define a series of concrete tasks in the description of the existing system structure, such as it is; in the projection of system requirements into the future; in the design of the component parts, functions and channels of information flow of the new system; and in the concrete realization and operational testing of this new system. All these tasks can be organized into checklists and sequences of suggested procedures. The systems designed so far have had to overcome varying degrees of difficulties before

smooth functioning was established. One general experience, however, tends to be of particular significance: the new system often has to cope with shocks and distortions which had not been anticipated during system design. At times, outside conditions and requirements change between the time of system design and final realization; at other times, it turns out that the importance of certain key factors had been underestimated. Such outcomes are sufficiently typical to suggest that they represent a normal condition of system development rather than a failure to follow an orderly procedure in system design. Therefore, when a new system is conceived, it has to be anticipated that some major shocks of an unforeseen nature may occur which will have a profound influence on the entire system between its design and realization. Accordingly, system design has to attempt to allow for the unforeseeable: it has to favor flexible systems over rigid ones, adaptive functions over pre-set ones, and it has to identify and protect by suitable buffers the elements of greatest vulnerability within the system. This principle appears to be fully applicable to the subsystems designed for industrial and general economic development planning.

B. The Role of Computers in Planning: Summary

59 The three aspects of industrial development planning discussed above - information flow, policy formulation, and system design - can in principle all be handled without high-speed information processing equipment. The task will, however, not only be facilitated tremendously if planning functions can be built around such equipment, but the volume of information flow, the sophistication of the models (especially their dynamic aspects) and the complexity of design and operation of flexible, adaptive planning subsystems can be carried incomparably further in the latter case. It is held that the combined effects of this added ease and greater potential complexity promise a fundamental breakthrough in regard to the entire problem of industrial development planning, and thereby constitute a key contribution of the information processing revolution to industrial growth in the less developed areas.

VI. Conclusion

60. Given the advantages discussed in the body of this paper, what proportion of the scarce resources of a country should be allocated to acquiring the new technology? No direct answer is possible at present, beyond the conjecture that a large, numerically controlled engineering fabrication facility, on the one hand, and a computer-based planning subsystem, on the other, are both likely to lead to net savings on account of every one of the three key scarce resources of the less developed areas - namely skills, foreign exchange and capital. This is asserted with the proviso that, first, concrete commitments be preceded by careful, comprehensive preliminary studies, and second, that the respective productive facilities or planning subsystems be staffed in adequate numbers by personnel trained on the job during a considerable period of initial operation.

61. In regard to the key tool employed by the new technology (i.e., the electronic computer with its auxiliary equipment) it should be noted that this machine itself belongs to the class of engineering products in whose production numerical control is now acquiring a major importance. Thus, the production of computers, or at least of significant portions of the complete machines, is a distinct possibility in the less developed areas. It should be admitted at the same time that the technological know-how needed for satisfactory applications, and especially for continued progress in this field, will probably have to be transferred from the industrialized countries for some time to come.

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